Global observing strategies

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Recent technological advances in space-based remote sensing, scientific information systems, and communications ensure global observing capabilities an essential role in contributing to the characterization, mitigation, and prevention of environmental problems that threaten human welfare. In addition, remote sensing capabilities can promote a more efficient and effective use of natural resources, thus minimizing some of the preconditions of environmental degradation and related crises.

Clearly, enhanced scientific understanding through improved information gathering is only one of many elements needed to meet sustainable development imperatives and forge stable international and intranational communities. But even the most simplified framework of key strategic interventions includes scientific, as well as sociological, political, and economic dimensions.

For the United States, specifically, Earth remote sensing offers numerous benefits that can be grouped beneath the umbrella of environmental security:

• Avoid commodity surprise: U.S. vulnerability to "surprise" in essential commodities can be reduced. The evolution of the global economy continues to increase U.S. involvement in global markets for food, energy, and other commodities. Information on the availability and quality of commodity supplies is not only essential for our security, but economically advantageous.

• Monitor critical instabilities: Regions at risk because of environmental or economic stress can be monitored in almost real-time for purposes of assessment, planning, and response management.

• Predict the weather: The impact of accurate, local, longer-range weather forecasts on disaster preparedness and response, agriculture, travel, even energy management would be very beneficial in terms of health and safety, property protection, and economic efficiency.

• Promote international cooperation: Increased cooperation among national and international organizations would accelerate technical progress on Earth monitoring and build international confidence in cooperative environmental issues. The evolution of an International Global Observation Strategy is a particularly important challenge.

Advances in space-based remote sensing

For national security reasons, civilian remote-sensing imagery did not in the past provide the spatial resolution that is required to assess many of the intense, small-scale environmental threats. The end of the Cold War has resulted in relaxed limits on the spatial resolution of civilian systems. Existing and soon to be launched scientific and commercial spaced-based imaging systems will provide both panchromatic and multispectral imagery that will resolve objects that are less than one meter in size. Geodetic accuracy of tens of meters and stereo-optic capability will also be common.

<u>Cloud penetration and improved spectral resolution.</u> Cloud cover and limited

spectral resolution of remote sensing systems no longer prevent monitoring of key environmental indicators. Remote sensing data are currently available from commercial and scientific optical, radar, and passive microwave measurements. Radar data can provide a wide variety of ecosystem and environmental measurements under all weather conditions, day and night. High spectral resolution measurements will become widely available within the next few years. High spectral resolution optical measurements show great promise for monitoring crop status, ecosystem health, and many environmental quality issues.

More frequent data updates. The current proliferation of Earth- observing satellite systems will mean that revisit times for imagery of any particular geographic location are being significantly reduced. Revisit times of less than five days are already available for many geographic locations.

Speedier data delivery. The rapid growth of the commercial remote sensing industry, along with increased scientific interest in using a wider range of data for operational environmental forecasting, has significantly increased the timeliness of remote sensing data delivery to the user. Products from most commercial imaging systems can now be delivered to the user in days. An increasing number of commercial sensors, and improvements in data transmission and processing infrastructure, will continue to reduce data delivery times, making possible such priority applications as crisis management.

International and commercial systems coming on line

Landsat is the best known, and continues to be a widely used, source of satellite data for environmental applications. Five Landsat satellites have been launched successfully by the United States since 1972. Landsat 6 was lost during launch. Landsat 7 will be launched in 1998. This series of satellites has provided a wealth of unique scientific information for studies of land cover and land-use change, geological mapping and analysis, urban and regional planning, and data for other research and commercial applications. Landsat data also serves some military planning and operations requirements such as traffic analysis and high-precision map making and terrain. Landsat's multispectral scanner with 50-meter resolution and its thematic mapper with 30-meter resolution have been widely used for scientific and commercial applications.

France was the second country to field a continuing, widely available surface imaging capability. The French satellite series, Satellite Pour l'Observation de la Terre (SPOT), has been in operation since 1986. The SPOT 1 satellite used charge-coupled device detectors with 10-meter panchromatic spatial resolution and 20-meter multispectral imagery.

Remote sensing imagery is now available from India, Russia, Canada, Japan, and the European Space Agency, all of which have active Earth observation programs. Brazil, Argentina, China, and several other nations plan to launch remote sensing instruments before the turn of the century. If all the government and commercial land imaging satellites are launched as currently planned, more than 15 satellites will be providing data in panchromatic, multispectral, and radar formats as soon as the year 2000. Table 13-1 provides basic information on most of the current and approved international land remote sensing satellites. The recent availability of all-weather surface

Table 13-1. New international land data satellites.

Country	Owner /OBJ	Program	Sched Date	Inst Type	Resolution in Meters P	M	R	#Color Bands	Stereo Type
FRANCE	G/O	Spot 5B	'04	P&M	5	10		4	F/A
U.S.	G/O	EOS AM-2 / L-8	'04	P&M	10	30		7	
FRANCE	G/O	Spot 5A	'99	P&M	5	10		4	F/A
INDIA	G/O	IRS-1 D	'99	P&M	10	20		4	C/T
U.S.	C/O	Space Imaging	'98	P&M	1	4		4	F/A
KOREA	G/O	KOMSAT	'98	P&M	10	10		3	F/A
U.S./JAPAN	G/O	EOS AM-1	'98	M	15	15		14	F/A
U.S.	G/O	Landsat-7	'98	P&M	15	30		7	
ESA	G/O	ENVISAT	'98	R			30	0	
U.S.	C/O	Space Imaging	'97	P&M	1	4		4	F/A
U.S.	C/O	Eyeglass	'97	P	1				F/A
FRANCE	G/O	Spot 4	'97	P&M	10	20		4	C/T
U.S.	C/O	EarthWatch	'97	P&M	1	4		4	F/A
U.S.	C/O	EarthWatch	'96	P&M	3	15		3	F/A
U.S.	G/E	CTA Clark	'96	P&M	3	15		3	F/A
U.S.	G/E	TRW Lewis	'96	P&M	5	30		384	
RUSSIA	G/O	Almaz 2	'96	R			5		
JAPAN	G/O	ADEOS	'96	P&M	8	16		4	C/T
CHINA-BRAZIL	G/O	CBERS	'96	P&M	20	20		7	C/T
CANADA	G/O	Radarsat	'95	R			9		
INDIA	G/O	IRS-1 C	'95	P&M	10	20		4	C/T
CHINA/BRAZIL	G/O	CBERS	'95	P&M	20	20		7	C/T
RUSSIA	G/O	Resours-02	'95	M		27		3	

NOTES:
Multispectral only — M
Pan & Multispectral — P&M
Panchromatic Only — P
Radar — R
Government Funded — G
Commercially Funded—C
Operational — O
Experimental — E
Fore & Aft Stereo — F/A
Cross Track Stereo — C/T

imaging capability using radar from Russian, Japanese, European, and Canadian satellites is a particularly significant recent advance.

The next few years will see a rapid growth in space-based commercial imagery systems. Several commercial organizations in the United States have announced plans to launch satellites with improved spatial resolution and more frequent revisit times than is available currently. The primary markets being targeted by commercial firms are urban and regional planning and agriculture. It is obvious that the imagery from such satellites can also support many environmental, military, and economic intelligence applications that are not time critical.

Technological trends in land remote sensing from space

The brief description above of selected Earth observation capabilities illustrates several important trends.

• There will be a proliferation of space-based sensors with enhanced atmospheric, land, and ocean imaging capabilities in the next few years. International spending on space has already reached substantial levels, is increasing, and cost-sharing agreements between governments are reducing the cost of access to space for new ventures.

• Commercial organizations are playing an increasingly important role as providers of imagery for both research and applications. Commercial imaging systems are also moving toward higher spatial resolution and faster data delivery than has been available from most government-operated systems.

• The increasing capability of civilian remote sensing in the areas of spatial resolution, spectral coverage, revisit time, and data-delivery time will dramatically enhance opportunities for environmental research and applications.

It should be clear that technology will not be a serious limiting factor to making progress on both domestic and international efforts to increase the effectiveness and efficiency of management of natural resources. High-precision agriculture and forestry are rapidly becoming a reality where private and state organizations can afford the price of the knowledge and technology. Widespread implementation of resource management tools that increase efficiency of use of inputs to production, such as, fertilizers and water, will significantly reduce pollution residuals. The United States has already made significant progress at reducing environmental threats on our own territory over the past several decades.

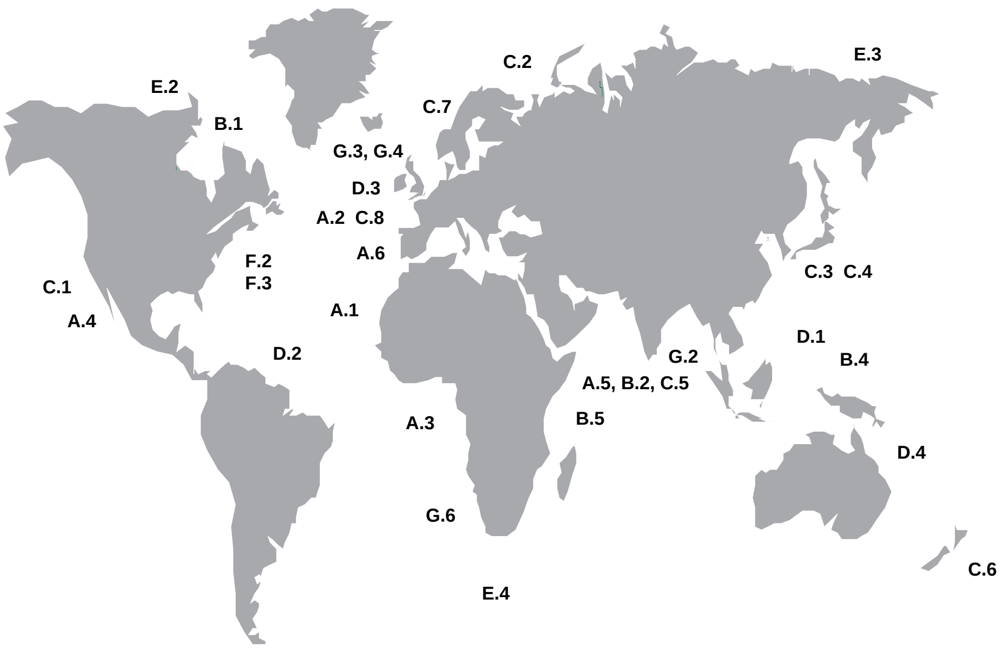
The diffusion of Earth remote sensing technologies to developing countries is limited primarily by the initial cost of data capture, data processing, and scientific information infrastructure. With major states like Russia, China, and India, which have near state-of-the-art capabilities, socioeconomic and political factors may be more important than technological capability.

Conclusions

Remote sensing data can contribute to the characterization, mitigation, and prevention of some natural resource and environmental degradation. A brief, qualitative summary of examples of recent applications of remote sensing to such problems is provided in Figure 13-1 and Table 13-2. These technologies and their applications are too new, and evolving too rapidly, to draw firm conclusions on their effectiveness for dealing with the entire range of environmental security issues. Still, several observations are supportable:

1. Remote sensing data can be a powerful tool for documenting change in land cover and land use. High spatial and spectral resolution satellite data will become widely available in the next few years, contributing to further advances in the descriptive analysis of changes in earth surface properties, such as topography, vegetation, and pollution.
2. Remote sensing can be useful for the rapid assessment of available natural resources, such as food, water, grazing lands, and biomass resources, that might cause or mitigate a crisis and lead to population migrations.
3. Integration of remote sensing data with surface weather and climate data, and with socioeconomic data in a geographic information system can contribute significantly to an understanding of spatial relationships between cause and effect variables, and to the understanding and anticipation of future conditions.

The expansion of commercial remote sensing industries around the world will accelerate progress on reducing local environmental threats. The commercial sector will



A *Agriculture*
A.1 ALIS - Egyptian agricultural land information service
A.2 Sugar beet monitoring
A.3 ARTEMIS - real time environmental monitoring in Africa
A.4 Inventory of agriculture and irrigated lands in Kansas
A.5 CAPE - crop acreage estimation and production forecasting in India
A.6 MARS - monitoring agricultural statistics in the EC

B *Resource management and surveying*
B.1 Geological structure identification and mapping
B.2 Drinking water provision for India's rural population
B.3 Offshore oil exploration
B.4 Tropical forest inventory
B.5 Vegetation data dissemination in Ethiopia

C *Hazard monitoring and disaster assessment*
C.1 Volcano hazard alert plan
C.2 Monitoring the Chernobyl disaster area
C.3 Earthquake prediction in China
C.4 Forest and grassland fire detection
C.5 NADAMS - agricultural drought assessment and monitoring
C.6 Damage assessment of cyclone in New Zealand
C.7 Oil spill monitoring using ERS SAR images
C.8 Flood monitoring and prediction using ERS I

D *Civil mapping and planning*
D.1 Natural resources mapping of the Philippines
D.2 Mapping of French Guyana
D.3 Land cover map of Great Britain
D.4 Landcover change in Australia

E *Ice monitoring*
E.1 Ice monitoring by the US National Ice Centre
E.2 Operational ice reconnaissance and forecasting in Canadian waters
E.3 Operational sea-ice monitoring on the Northern Sea Route
E.4 Real-time ice monitoring in the Antarctic

F *Coastal zone management*
F.1 Coast Watch
F.2 Coastal change analysis
F.3 Coastal development monitoring on the Georgia-South Carolina seaboard

G *Oceanographic applications*
G.1 Fishery utilization of remote sensing data in Japan
G.2 Fishing zone forecasting in India
G.3 Offshore pipeline routing
G.4 Sea state forecasting for offshore operation
G.5 Ship route optimization using ERS data
G.6 Real-time monitoring of potential fisheries (Lake Malawi and Namibia)

Figure 13-1. Examples of remote sensing applied to problems of environmental security.

focus on reducing costs and ensuring timely data delivery. State research organizations will conduct the basic research necessary for radically new applications.

Table 13-2. Brief summaries of remote sensing capabilities referenced to the environmental security applications given in Figure 13-1.

Instrument (platform)	Application (project index)	Instrument type	Instrument characteristics
AMI Scatterometer mode (ERS-1)	G 4	Wind scatterometer	Waveband: Microwave: 5 3GHz. C-band, VV polarisation Spatial resolution: Cells of 50km x 50km at 25km intervals Accuracy: Wind direction: ±20° Wind speed: ±2m/s or 10% Duty cycle: Depends upon the use of AMI for SAR images Swath width: 500km Date rate: 500kbps
AMI-SAR Image mode or wave mode (ERS-1)	A.6, B.1, B.3, C.7, C.8, D.2, E.1, E.2, E.3, E.4, G.3, G.4, G.5	Imaging radar	Waveband: Microwave: 5.3GHz, C band, VV polarisation Spatial resolution: 30m; Duty cycle: 10% nominal for image mode, wave mode depends on the use of AMI for SAR images Swath width: Image mode: 100km, Wave mode: 5x5km at 200km intervals Data rate: 105Mbps (image); 370kbps (wave mode)
AVHRR Advanced Very High Resolution Radiometer (NOAA)	A.3, A.6, B.5, C.1, C.3, C.4, C.5, D.4, E.1, E.2, E.3, E.4, F.1, G.1, G.2, G.6	Imaging multi-spectral radiometer (visible/IR)	Waveband: Visible: 580-680nm, NIR: 725-1100nm, SWIR: 3.55-3.93µm, TIR: 10.3-11.3µm, 11.4-12.4µm Spatial resolution: 1.1km (ssp). Compressed Global Area Coverage (GAC) data recorded at 4km resolution Swath width: 3000km (approximate) 55.4 deg scan off nadir Duty cycle: 100% Data rate: 66.5kbps for GAC, 665.4kbps for HRPT
HRV High Resolution Visible (SPOT)	A.1, A.2, A.6, B.4, C.2, C.6, C.8, D.1	High resolution imager	Waveband: Visible: 500-590nm, 610-680nm NIR: 790-890, Panchromatic 510-730nm Spatial resolution: 10m (panchromatic) or 20m Duty cycle: Daylight coverage only (world wide coverage using on board tape recorder). 100% in daylight. 26 day orbital cycle Swath width: 117km (ie 60+60km with 3km overlap). Data rate: 25Mbps There are two identical HRV instruments on SPOT each of which can point off-track by ±27° enabling stereoscopic coverage.
LISS I/II Linear Image Self-Scanning System (IRS 1A/1B)	A.5, B.2, C.5	High resolution imager	Waveband: Visible: 460-520nm 520-590nm 620-680nm NIR: 770-860nm Duty cycle: 100% (daylight). Revisit time 22 days (11 days both) Spatial resolution 72 5m (LISS I), 36 25 (LISS II) Swath width 148km (LISS I), 145km (LISS II) Data rate 5 2Mbps (LISS I), 2×10 4Mbps (LISS II)

Table 13-2. (Continued.)

Instrument (platform)	Application (project index)	Instrument type	Instrument characteristics
MESSR Multispectral Electronic Self Scanning Radiometer (MOS 1b)	B 4	High resolution imager	Waveband: Visible 510-590nm 610-690nm NIR: 730nm-800nm 800nm-1100nm Spatial resolution: 50m Swath width: 100km (200km when both camera systems are operating) Data rate: 9Mbps
MSS Multi-spectral Scanning System (LANDSAT)	A.5, B.4, D.4, F.3	High resolution imager	Waveband: Visible: 500-600nm 600-700nm NIR: 700-800nm 800-1100nm Spatial resolution: 80m in visible and NIR channels Duty cycle: 30% Swath width: 185km Data rate: 15Mbps
MSU-E Multispectral Scanner Electronic scanning (Resource)	C.2	High resolution imager	Waveband: Visible: 500-600nm 600-700nm NIR: 800-900nm Spatial resolution: 45m (at nadir) Accuracy: 4% radiometric accuracy Duty cycle: Programmable Swath width: 45m (one scanner), 80m (two scanners); pointable ±30° from nadir Data rate: 11Mpbs (3 channels)
MSU-SK Multispectral Scanner conical scanning (Resource)	C.2	Imaging multi-spectral radiometer (visible/IR)	Waveband: Visible: 550-600nm 600-700nm NIR: 700-800nm 800-1100nm TIR: 10.3-11.8μm Spatial resolution: Visible-NIR: 170m TIR: 600m Accuracy: 4% radiometric accuracy Duty cycle: Programmable Swath width: 600km Data rate: 11.5Mbps (5 channels)
Multispectral Visible and IR Scan Radiometer (10 channel) (FY-1)	C.3	Imaging multispectral radiometer (visible/IR)	Waveband: Visible: 430-480nm 480-530nm 530-580nm 580-680nm NIR: 840-490nm 900-965nm 1.58-1.68μm SWIR: 3.55-3.93μm TIR: 10.3-11.3μm 11.5-12.5μm Spatial resolution: 1.1km Duty cycle: 100% Swath width: 3200km Data rate: 1.3308Mbps
MVIRI METEOSAT Visible and Infra-Red imager (METEOSAT)	A.3, B.5, C.1	Imaging multispectral radiometer (visible/IR)	Waveband: Visible: 500-900nm TIR: 5 7-7 1μm (water vapour 10.5-12.5μm Spatial resolution: Visible: 1 25km TIR: 5km (after processing) Duty cycle: Full Earth in all three channels, every 30 min Swath width: Full Earth disc Data rate: 333kbps

Table 13-2. (Continued.)

Instrument (platform)	Application (project index)	Instrument type	Instrument characteristics
OLS Operational Line-scan (DMSP)	E.1	Operational line-scan System (visible to near IR/thermal IR)	Waveband: Visible 400-1100nm TIR 10.5-12.5μm Spatial resolution: TIR 560m Duty cycle: 100% Swath width: 3000km
RA Radar Altimeter (ERS-1)	B.3, E.4, G.4, G.5	Radar altimeter	Waveband: 13.8GHz, K band Spatial resolution: 7km Accuracy: Wave height: 0.5m or 10% (whichever is smaller) Sea surface elevation, better than 10cm Duty cycle: 100%
SSM/I Special Sensor Microwave Imager (DMSP)	E.1, E.2, E.3, E.4	Passive microwave imager	Waveband: 19.35GHz, 22.23GHz, 37GHz, 85.5GHz Spatial resolution: 25-50km Swath width: 1394km
TM Thematic Mapper (LANDSAT)	A.2, A.4, A.6, B.2, B.4, C.2, C.8, D.3, F.2, F.3	High resolution imager	Waveband: Visible: 450-520nm 520-600nm 600-690nm NIR: 760-900nm SWIR: 1.55-1.75μm 2.08-2.35μm TIR: 10.4-12.5μm Spatial resolution: Vis and SWIR: 30m TIR: 120m Accuracy: Radiometric: 10% Geometric: 500m Duty cycle: 30% Swath width: 185km Data rate: 84.9Mbps
VISSR Visible and Infra-Red Spin Scan Radiometer (GMS)	C.1, C.3	Imaging multispectral radiometer (visible/IR)	Waveband: Visible: 550-900nm TIR: 0.5-7.00μm 10.5-11.5μm 11.5-12.5μm Spatial resolution: Visible 1.25km, IR: 5km Duty cycle: Full Earth all channels every hour Swath width: Full Earth disc
VISSR & VAS Visible and Infra-Red Spin Scan Radiometer/ Atmospheric Sounder (GOES 7)	C.1	Imaging multispectral radiometer (visible/IR) and Atmospheric sounder	Waveband: Imaging: Visible: 550-750nm TIR: 11.0μm ± 2 IR selectable from 3.9, 6.7, 7.3, 12.7 and 13.3μm Sounder: 1 visible and 12 IR: (3.9 to 14.7μm) Spatial resolution: Visible: 1km IR: 7km and 14km Duty cycle: 100% Swath width: Horizon to horizon Data rate: 240Mbps